Int. Agrophysics, 2004, 18, 91-96

INTERNATIONAL
Agrophysics
www.ipan.lublin.pl/int-agrophysics

Influence of the soil penetration resistance, bulk density and moisture on some components of winter wheat yield

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Received October 27, 2003; accepted November 24, 2003

A b s t r a c t. The influence of bulk density, penetration resistance and moisture content in the upper layers of soil profile (0-25 cm) on variability of yield components of four winter wheat cultivars was studied. Experiments were carried out on soil of good rye complex. Analyzed were following features of the yield structure: height of plants, number of ears on a square meter, number and weight of grains in an ear, length of ear and weight of 1000 grains. Variable temperature and precipitation during the vegetation period were found to have brought about considerable differences in variability of physical soil features analyzed. Analysis of multiple regression proved that the wheat yield was most dependent on the weight of grains in an ear. Less influence was of 1000 grains weight, number of ears on a square meter and number of grains in an ear. Partial correlation coefficients of penetration resistance and moisture pointed to negative relationship between physical soil features and the wheat yields. The analysis of canonical correlation showed that variability in the yield components studied depended up to 47% on three basic physical parameters of soil. The greatest influence on variability of the yield components was exerted by moisture and then by penetration resistance of soil. Decreased soil moisture brought about mainly a reduction in the number of ears on a unit of area.

K e y w o r d s : penetration resistance, moisture, soil bulk density, yield components

INTRODUCTION

The wheat yield from a unit of area depends mainly on the number of ears, number and weight of grains in an ear and weight of 1000 grains. Correlations between the yield, weight and number of grains in an ear are most often high (Mahdy 1988). However, though the relationship between the weight of 1000 grains and the yield shows a positive correlation, but most investigators emphasize a high influence of the environment on this yield component (Sigh *et al*., 1992; Budak and Yildirim, 1999; Mittler, 2000). In many publications there is also emphasized a positive relationship between the height of plants and the yield of grain (Podolska, 1999; Sip and Skorpik, 1980). Shpiler and Blum (1986) prefer selection in respect of the ear length in connection with increased number of grains in an ear, regarding just this component as contributing to increased productivity of wheat cultivars. The above component is most often positively correlated with the number of grains in an ear which in little degree is subject to plant competitiveness (Silis 1986). Peszek *et al*. (1985) say that the number of grains in an ear is the basic element of grain weight in an ear, which with about 30 grains should be in the range of 40-50 g. Kuś *et al*. (1993) report that on soils of good wheat complex yields amounting to 80-95 q ha^{-1} are possible to be obtained with 550-650 ears m^{-2}, about 30 grains in an ear and 43-48 g of 1000 grains weight. Significant influence on this yield component is exerted by the number of ears per a square meter as well as the number of grains in an ear (Blue *et al*. 1990). Although the yield of grains in an ear is a complex feature, determined through mutual relations between the number of ears and their fertility, but many breeders advance just this component as first in developing new intensive wheat cultivars (Milczak and Smietana, 1997; Gużow, 1986). However, most authors point to much differentiated correlations between the yield components, which depend mainly on the cultivar (Bielawska, 1999; Mądry, 1993) and conditions of the experimental environment (Pearson, 1994; Weber 2000).

The yield of plants is conditioned, too, the physical properties of soil. Crucial influence of the mode of tillage on compaction or loosening of the surface soil layers has been emphasized in many papers (Ball-Coelho *et al*., 1998;

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Dzienia *et al*., 1995; Mielke and Wilhelm, 1998). It is most often that compacted soil is characterized by worse retention ability as compared to loosened one (Dzienia *et al*., 1995; Laddha and Totawat, 1997), though the top part of the humus horizon of compact soil under zero tillage can be more moist than that of loosened soil under conventional tillage. The negative effects of soil compaction appear merely during its drying up (Ball and Ritchie, 1999; Hussain *et al*., 1999). The yield depends on the degree of soil compaction, though it is not always that increased compaction brings about a decreased yield (Dauda and Samari, 2002). Compaction of soil is most often the measure of the root system development. During the vegetation of plants, in effect of contraction, influence of atmospheric factors and kneeding, compaction in the upper soil layers reaches the values from 1.5 to 5 MPa (Manor *et al*., 1991; Burt *et al*., 1994). As it appeared in investigation, relationship between the factors forming the condition of soil on one hand and its physical properties and yield on the other was found difficult to be determined (Canarache, 1990; 1991; Sigh *et al.,* 1992). It depends mainly on the soil type, water-air relation, abundance in nutrients and distribution of precipitations during the period.

This research was required to find:

1. What is the range of interaction of soil penetration resistance, density and moisture (independent variables) on selected components of winter wheat yield (dependent variables)?

2. Which of the independent variables set explains the maximum range of variability of selected yield components?

3. Which independent variables considered jointly explain the largest range of variability of the dependent variables set?

CONDITIONS AND METHODS

Cultivation, Jelcz-Laskowice, in the years 1999-2002 on soil of good rye complex. Following modes of tillage were applied :

- post-harvest – grubber to 15 cm depth + cage roller,
- basic – ploughing to 25 cm depth + harrow,
- pre-sowing – cultivation aggregate (cultivator + cage roller) herbicides according to requirement.

In conditions of conventional cultivation four winter wheat cultivars were sown after three different forecrops, namely: Elena, Maltanka, Kobra and Izolda. The size of a plot was 110 m^2. Physical properties of the soil were examined during propagation, shooting, flowering and milk maturity, the determinations being made separately for each treatment. Differentiated atmospheric conditions (temperature, rainfalls), which exerted a significant influence on variation in physical parameters of the soil, have been presented in Table 1. Measurements of the soil moisture were taken by means of a neutron probe type CPN Hydroprobe twice in a month during the vegetation of wheat. The moisture was measured at the depths of soil profile from 0 to 25 cm. Soil density was determined so that not to disturb the structure of soil, taking samples into 100 cm^3 cylinders from three depths 0-5, 5-10, 10-20 cm. Measurements of soil penetration resistance (0-20 cm) were taken by means of a drop-cone penetrometer with a 2.17 kg plummet and a cone detector with 24 mm diameter and 30 apex angle.

The mean moisture, penetration resistance and densities of soil from each plot during the vegetation of wheat were compared with selected components of the yield. They were: height of plants, number of ears on 1 square meter, number of grains in an ear, weight of grains in an ear, weight of 1000 grains and ear length. Mineral fertilization and nursing measures were carried out to generally accepted standards.

T a b l e 1. Mean precipitation (mm) and temperature (°C) in the growing season of wheat

Precipitation Temperature	Months					
	III	IV	V	VI	VII	VIII
Many-years' mean precipitation	30.3	36.1	63.7	70.8	77.4	69.9
Deviation from means (mm) 1999	+27.4	-20.3	-18.1	+8.3	+10.6	+17.2
Deviation from means (mm) 2000	+46.4	-18.9	+12.8	-32.7	-60.0	+113.7
Deviation from means (mm) 2001	+30.0	+4.8	+5.1	+0.4	+63.4	+10.1
Deviation from means (mm) 2002	-18.4	+22.1	+15.7	-17.1	-22.6	-13.4
Many-years' mean temperature	3.1	8.0	13.3	16.6	17.8	17.3
Deviation from means (0C) 1999	+1.9	+1.6	+0.7	0.0	+2.1	+0.4
Deviation from means (0C) 2000	+1.6	+3.8	+2.3	+0.3	-0.1	+2.3
Deviation from means(0C) 2001	+0.1	+0.3	+1.5	+1.5	+1.4	+1.3
Deviation from means (0C) 2002	+1.9	-0.3	+3.9	+1.5	+2.6	+2.8

For a complex assessment of the influence of three physical features of soil on the selected yield components there was applied canonical analysis as described by Krzyśko and Ratajczak (1978) and Johnson and Wichern (1988). Statistical analysis was made by means of the Statistica program.

RESULTS AND DISCUSSION

The range of variability in penetration resistance, bulk density and moisture of soil are presented in Table 2. Whereas the mean values of three basic physical properties of the soil and components of winter wheat yield are shonw in Table 3. To determine the influence of selected yield components and physical properties of soil on the yielding of wheat, introductory multiple regression analysis was made which resulted in the following equation:

$$Y=0.12WR + 0.29LK - 0.02DLK + 0.27LZK + 0.74MZK + 0.27MTZ - 0.21ZW - 0.08GS - 0.19WL - 140.2,$$

where: LK – number of ears per square meter; WR – height of plants; DLK – length of ear, cm; LZ – number of grains; MZK – weight of grain in an ear, g; MTZ – weight of 1000 grains, g; ZW – soil penetration resistance, MPa; GS – soil density, g cm^{-3}; WL – soil moisture, % vol.

Multiple regression determination coefficient R^2 = 0.802.

The yields of cultivars from a plot were found to depend mostly on the weight of grain in an ear. Much less influence on their yielding was that exerted by the number of grains in an ear, weight of 1000 grains and number of ears on a unit of area. Note – worthy are the negative partial correlation coefficients of soil compaction and moisture, which point to negative interdependence with the yields of wheat. The quantity of determination coefficient for multiple regression (R^2 = 0.80) indicates that the variation of yield was in 80% determined by the set of the features analyzed. For determination of the connections between the physical properties of soil and the components of yield structure canonical analysis reveals new hidden canonical variables being weighed sums of the two sets analysed. High canonical correlation (R = 0.78) between the sums of the va- riables analysed (i.e., canonical roots) points to high interdependence between the physical properties of soil and the selected components of yield (Table 4). However, total redundancy of the set of physical soil properties indicates that the soil properties analysed influence variation in the components of winter wheat yield up to 47%. Roots – canonical variables explain a determined part of variability in the data collection analysed. Successive canonical variables are computed so that each next root determines an additional part of the variability. Canonical variables are not correlated with each other and present lower and lower percentage in total variance of the set. Table 5 shows estimation of the significance of canonical variables in the set of physical soil properties and components of the wheat yield.

Table 2. The range of variability in penetration resistance, bulk density and moisture content in the upper soil layer (0-25 cm) depending on the year of study

Year	Penetration resistance (MPa)	Bulk density (g cm^{-3})	Moisture (% vol.)
1999	1.37-2.04	1.41-1.76	6.2-14.8
2000	1.99-2.96	1.38-1.65	4.9-12.3
2001	0.89-3.06	1.55-1.79	7.8-15.2
2002	1.14-3.56	1.51-1.68	5.3-13.9

Table 3. Mean values of soil compaction, density, moisture and components of winter wheat yield in the years 1999-2002

Cultivar	Yield kg plot^{-1}	LK	WR	DLK	LZ	MZK	MTZ	ZW	GS	WL
Aleta	55.5	483.3	80.2	9.1	40.5	2.0	46.9	2.07	1.62	8.34
Elena	57.5	469.1	83.4	9.4	51.8	2.2	40.4	1.77	1.61	8.70
Kobra	64.2	505.2	79.2	8.4	45.7	2.3	45.5	2.20	1.58	9.14
Izolda	59.9	502.6	85.6	10.1	53.3	2.4	44.4	2.04	1.59	8.63

LK – number of ears on a square meter; WR – height of plants; DLK – length of ear, cm; LZ – number of grains; MZK – weight of grain in an ear, g; MTZ – weight of 1000 grains, g; ZW – soil penetration resistance, MPa; GS- soil density, g cm^{-3}; WL – soil moisture, % vol.

On the ground of significant values obtained in test Chi^2 it can be stated that the analysis should take into ac- count only the two first canonical roots. The above conclu- sion has been corroborated, too, by the low value of lambda statistics concerning those roots. Thus the interdependence between the set of variables can be described by means of two pairs of canonical variables, as it was only between those values that significant canonical correlations had been proved. The first canonical root for the physical parameters of soil (independent variables) determines 44% variation of the set examined (Table 6). However, variance in wheat yield components isolates 65% of the total variance in dependent variables. Redundancy of a given canonical variable shows how much of average variance in one set is explained by the given canonical variable in the other set. Redundancy of first canonical variable for the physical features of soil is 0.398, so this variable explains 40% variation in the yield components analysed. The other canonical roots are characterized by much lower values of separated variance and redundancy.

The preliminary analysis of simple correlations between the physical parameters of soil and winter wheat yield components (Table 7) points to significant interdependence between the soil penetration resistance and number of ears per a square meter, height of plants, as well as the number of grains in an ear. Similarly, soil moisture is correlated positively with the number of ears per a square meter, height of plants and weight of 1000 grains.

The total redundancy of the set of physical soil features indicates that the soil properties analysed influence the variation of winter wheat yield components in 47%. More complex information is to be obtained through learning the structure of the two first variables. The roots-canonical variables explain a determined part of variation in the data collection analysed. Successive canonical variables are computed so that each next root would determine an additional part of variation. The canonical variables are not correlated with each other and present lower percentage of total variance of the set. Table 4 shows estimation of the significance of

T a b l e 4. Juxtaposition of the results of canonical analysis

Number of variables	Separated variance (%)	Total redundancy (%)
Physical properties of soil – 3	100.0	47.3
Yield components – 6	70.8	35.6
R canonical = 0.784, Chi^2 = 70. 803, p.= 0.0001		

T a b l e 5. Chi^2 tests – estimate of the canonical variables squared

Root removed	R canonical	R^2 canonical	Chi^2	p. level	Primary lambda
0	0.784	0.614	70.90	0.00001	0.184
1	0.700	0.491	30.82	0.0006	0.480
2	0.239	0.057	2.48	0.646	0.942

T a b l e 6. Parts of separated variance and the redundancy of physical soil properties and wheat yield components

Factor	Separated variance for the set of independent variables	Separated variance for the set of dependent variables	Redundancy of the set of dependent variables
Root1	0.445	0.647	0.398
Root2	0.156	0.128	0.062
Root3	0.107	0.225	0.012

T a b l e 7. Correlation of physical soil properties with the components of winter wheat yield

Features	LK	WR	DLK	LZ	MZK	MTZ
ZW	–0.61*	–0.63*	–0.32	–0.51*	–0.43	0.24
GS	0.44	0.49	0.30	0.25	0.20	–0.18
WL	0.69*	0.60*	0.07	0.37	0.29	0.59*

*Significant at p = 0.05.

canonical variables in the set physical soil properties and components of the wheat yield. Partial coefficients of the weighed sums of dependent and independent variables ($a_1X_1 + a_2X_2 + a_3X_3$ and $b_1Y_1 + b_2Y_2 + ... b_6Y_6$) are called canonical weights. They are given for standardized variables of set X (physical soil features) and set Y (wheat yield components). The higher is the absolute weight, the greater contribution of a given dependent or in-dependent variable to the canonical variable analysed. The greatest contribution in forming the first canonical variable is that of soil moisture in the first data collection and the number of ears per a square meter in the second one (Table 8).

The canonical analysis presented has proved the components of winter wheat yield to be conditioned by three basic physical parameters of soil. The remaining unexplained variation percentage of the yield structure analysed could have been due to different sowing dates in particular years, forecrops, atmospheric conditions, mycotic diseases, quality of the sowing material or dates of nitrogenous fertilization applied. Reaction of wheat cultivars to the doses of nitrogenous fertilization is different (Podolska and Stankowski, 2001). A part of them produce maximum yield with lower total doses of nitrogen while others with significantly higher ones. Different dates of sowing could have been also important to formation of several yield components. As proved experimentally, delayed sowing was bringing about various changes in the number of ears on a unit of area, in the number of grains in an ear and in the weight of 1000 grains (Podolska and Mazurek, 2000; Hotsonyame and Hunt, 1997). However, an important part in variation of the parameters of yield structure was played by atmospheric conditions – temperature during the vegetation of wheat and distribution of atmospheric precipitations (Mittler 2000). Baviec and Bavec (1995) found that change in the productivity of crops at different density of sowing was more dependent on light than on the feeding area. The greatest influence on variation in the components of yield structure was exerted by moisture, and then by compaction of soil. The decrease in soil moisture brought about, first of all, a reduction of the number of ears on a unit of area. Podolska's investigation results point to soil moisture being the essential yield-forming factor (Podolska *et al*., 2002). Higher soil compaction was found to limit the number of ears per a square meter and, in a less degree, to influence variation in the number of grains in an ear and weight of 1000 grains.

T a b l e 8. Canonical weights of the physical properties of soil and the components of wheat yield

Canonical variable	Root1	Root2	Root3
Physical properties of soil			
Compaction	0.27	–1.23	0.78
Density	–0.22	0.31	1.02
Moisture	–0.68	–1.29	0.09
Yield components			
Number of ears per m^2	–0.60	0.41	–0.55
Height of plants	–0.21	0.27	0.89
Length of ear	0.15	0.40	0.70
Number of grains in an ear	–0.32	0.66	–1.15
Weight of grains in an ear	–0.05	–0.64	–0.09
1000 grains weight	0.13	–1.22	–0.38
Eigen - values	0.61	0.49	0.06

Thus, the correlation between the number of ears per a square meter and the soil moisture was the basic factor of canonical correlation between the data collections analysed. The variables – penetration resistance and soil moisture in the first set as well as the weight of 1000 grains and number of grains in an ear in the second one – contribute most in forming the second canonical variable. Significant influence on soil moisture on the number of ears per a square meter as well as that of soil moisture and penetration resistance on the number of grains in an ear and 1000 grains weight is confirmed by simple correlations occurring between those variables as well as by correlations (factorial charges) between the canonical roots and the factors analysed in each set. The least influence on variation in the components examined was exerted by soil density, the latter having been also characterized by less influence on yields of the cultivars tested. The analysis allows, too, of computing so called own values, which should be interpreted as percentage variance explained through canonical correlations between respective canonical variables. Square roots of each own value determine canonical correlations between the canonical variables analysed.

CONCLUSIONS

1. The analysis of the canonical correlation showed that variability in the yield components studied depended up to 47% on three basic physical parameters of soil.

2. The greatest influence on variation in the yield structure components was exerted by moisture, and then by the soil resistance to penetration.

3. A decrease in soil moisture mainly brought about a reduction in the number of ears per unit of area.

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